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COOL-COLOR ROOFING MATERIAL ATTACHMENT 7: TASK 2.6.1 REPORTS - BUILDING ENERGY-USE MEASUREMENTS AT CALIFORNIA DEMONSTRATION SITES

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

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Lawrence Berkeley National Laboratory and Oak Ridge National Laboratory

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

June 2006
CEC-500-2006-067-AT7

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California Home Demonstrations Showcasing the Energy Savings of Tile, Painted Metal and Asphalt Shingle Roofs with Cool Color Pigments

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ABSTRACT

Aesthetically pleasing dark roofs can be formulated to reflect like a highly reflective "white" roof in the near infrared portion of the solar spectrum. New paint pigments increase the near infrared reflectance of exterior finishes by minimizing the absorption of near-infrared radiation. The boost in the NIR reflectance drops the surface temperatures of roofs and walls, which in turn reduces cooling-energy use and provides savings for the homeowner and relief for the utilities. The new cool color pigments can potentially reduce emissions of carbon dioxide, which in turn reduces metropolitan heat buildup and urban smog. Energy savings are particularly pronounced in older homes having little or no attic insulation, especially if the attic contains poorly insulated ducts. Cool roofs also result in a lower ambient temperature that further decreases the need for air conditioning, retards smog formation, and improves thermal comfort.

Residential demonstrations consisting of three pairs of single-family, detached houses were set up with concrete tile, painted metal and asphalt shingle roofs to showcase the energy savings of cool-pigmented roofs. For each pair of homes, one was roofed with a cool-pigmented product and the other roofed with a conventionally (warmer) pigmented product of the same color. Measured temperatures and heat flows at the roof surface, within the attic and at the ceiling of the houses are discussed as well as the power usage to help gauge the cost savings afforded by cool-pigmented reflective roof products.

INTRODUCTION

Dark colors are not necessarily dark heat absorbers! Dark colors can be formulated to reflect like a highly reflective "white" color in the NIR portion of the solar spectrum that ranges from 700 to 2,500 nm. Brady and Wake (1992) found that 10 µm particles of TiO_2, when combined with colorants such as red and yellow iron oxides, phthalocyanine blue, and perylene black, could be used to formulate fairly dark colors with near-infrared reflectance of 0.3 and higher. Researchers working with the Department of Defense added complex inorganic color pigments (CICPs) to paints used for military camouflage and matched the reflectance of background foliage in the visible and NIR spectra. The chlorophyll in plants strongly absorbs in the non-green parts of the visible spectrum, giving the leaf a dark green color with high reflectance elsewhere in the solar spectrum[1] (Kipling 1970). In the NIR the chlorophyll in foliage naturally boosts the reflectance of a plant leaf from 0.1 to about 0.9, which explains why a dark green leaf remains cool on a hot summer day. Tailoring CICPs for high NIR reflectance similar to that of chlorophyll provides an excellent passive energy saving opportunity for exterior residential surfaces such as roofs exposed to the sun's irradiance. A CICP consisting of a mixture of the black pigments chromic oxide (Cr_2O_3) and ferric oxide (Fe_2O_3) increases the solar reflectance of a standard black pigment from 0.05 to 0.26 (Sliwinski, Pipoly & Blonski 2001).

Three pairs of residential demonstrations were established in California for documenting the potential energy savings for single-family detached homes having roofs painted with cool pigmented colors. Two pair of homes were constructed with concrete tile and painted metal roofs with and without cool pigmented colors. Another pair of homes demonstrated asphalt shingles with and without cool pigmented colors.

The California utilities are keenly interested in knowing the amount of electrical energy savings that would occur if roofs with cool pigmented colors, termed here on as cool roof color materials (CRCMs), are adopted in the building market. Our primary objective then is to demonstrate the thermal and potential economic benefits of CRCMs. The reported results also provide the confidence the utilities are seeking for making economic decisions on rebates for cool roof products.

DEMONSTRATION HOMES

It was difficult to estimate the time and effort required to convince a building contractor to accept, install, instrument, and monitor prototype tile, painted metal or asphalt shingle roofs on homes under construction in the Sacramento area. Timing was critical because a six month lead time is typically needed for obtaining city and county building permits. The Sacramento Municipal Utility District (SMUD) was offering through its Advanced Technologies Program to subsidize homes built with insulated concrete form (ICF) walls. LBNL and ORNL were interested in energy efficient roofing and it made good sense to combine the two initiatives and work together on the performance of the building envelope. Evans Construction agreed to partner with ORNL, SMUD, Hanson Roof Tile and Custom-Bilt Metals. A Memorandum of Understanding (MOU) was approved by ORNL, SMUD and Evans Construction for setting up two concrete tile and two painted metal roofs on residential homes built in the Cavalli Hills subdivision of Fair Oaks, CA (Appendix A).

Cavalli Hills is a twelve-lot subdivision having three different house designs (A-, B- and C-style floor plans) with footprints respectively of 120, 130 and 149 square meters (1300, 1400 and 1600 square feet),Fig. 1. A pair of A-style homes each identical in floor plan, layout and equipment design and having 1400 square feet of floor space had identical concrete tile roofs of the same color with and without CRCMs. A second pair of identical C-style homes having 1600 square feet of floor space had identical painted metal shake roofs of the same color with and without CRCMs.

The two pairs of homes in Cavalli Hills constructed with ICF walls also used advanced air-conditioning as part of SMUD's Customer Advanced Technologies field study and rebate program. The ICF walls were made using expanded polystyrene insulation (EPS) forms

[1] except for some bands of radiative absorption by water.

connected with polypropylene ties. Concrete was poured into the erected forms to complete the wall systems. The ICF walls had an overall thermal resistance (R-value) of about 16 hr•ft^2•°F/Btu. Each house is heated by a conventional 90% efficient gas furnace and hot water is supplied by a gas hot water heater. Comfort cooling is provided by split-system FREUS™ air-conditioners. The FREUS™ unit uses water stored in the basin of the outdoor unit and sprays it onto the condenser coils of the outdoor unit (as is commonly done with large commercial cooling equipment). The falling film of water accepts condenser heat and falls back into the reservoir. Any evaporated water is replenished. The evaporative cooling cycle is more efficient than conventional air-cooled equipment.

We intended to field test asphalt shingle roofs at Cavalli Hills as mentioned in the MOU (Appendix A); however, the demand for single-family detached housing caused Evans to accelerate construction and finish all twelve homes before prototype asphalt shingles were available for field testing. SMUD again provided help by trying to win the interest of builders, but the building community in and around Sacramento communicated their preference for concrete tile products. The F. W. Dodge (2002) report revealed that the asphalt shingle industry commands about 86% of the national market; however, in the Pacific Coast region the market share is down at about 75% because of the popularity of concrete and clay tile products. Neither Mercy Housing nor Habitat for Humanity could take advantage of our offer for donated roof materials plus free labor to install.

Elk Corp. had at this point in time developed prototype shingles and worked through their manufacturing representatives to locate a residential site in Redding, CA for demonstrating their new asphalt shingles with and without CRCMs. The firm Ochoa and Shehan Inc. agreed to demonstrate asphalt shingle roofs on two new homes of identical footprint, layout and equipment design. A MOU was written and approved by Elk Corp., Ochoa and Shehan Inc. and ORNL (Appendix B). The Redding site was considered an excellent selection for field testing asphalt shingles because the outdoor ambient air temperature in Redding often peaks at 43.3°C (110°F) during the summer, and winters typically experience sub-freezing outdoor temperatures.

The Cavalli Hill demonstration homes ventilated the attic using soffit and gable vents. R-19 loose fill insulation was blown in the attic space and the indoor air-handler and air-distribution ducting are in the attic. All ducts were wrapped in R-5 insulation. The homes in Redding also have soffit and ridge ventilated attics. For them, R-19 loose fill insulation was blown in the attic space and the indoor air-handler and air-distribution ducting is in the attic. Orineted strand board (OSB) decking facing the attic interior uses a radiant barrier as required by the building codes for the county of Redding.

Homes Showcasing Concrete Tile Roofs

Hanson Roof Tile donated its medium profile Hacienda concrete tile for the two A-style demonstration homes in the Cavalli Hills subdivision (Fig. 1). Evans Construction contracted Dynamic Roofing to install the tile. ORNL personnel worked with Evans and Dynamic Roofing to set up temperature measurements of the roof. Installation included a roof deck made of 5/8 in oriented strand board (OSB); 30-lb saturated asphalt felt paper and 1-in by 1-in battens for offset mounting the tile to the OSB deck (Fig. 2). Evans selected the Hacienda tile with chocolate brown color, which has a solar reflectance of only 0.10 and thermal emittance of 0.93. Ferro worked with Hanson Tile to increase the solar reflectance of the Hacienda tile and observed that adding cool color pigments to the sand, cement[2], and water mixture during the manufacturing process required excessive amounts of pigment making the product too expensive. The process also diluted the surface color. Ferro developed a slurry coat application that put the reflectance upwards of 0.40. However a parallel initiative by American Rooftile Coating proved to be more successful and economical. They painted their COOL TILE IR COATING™ onto several samples of concrete tiles of different colors (Fig. 3). The solar reflectance of the chocolate brown Hacienda tile exceeded 0.40 and was applied to the second A-style home for demonstrating the benefits of the CRCMs. The application applies a white undercoat followed by a chocolate brown topcoat. Figure 4 shows the completed job of the tile with coating applied by American Rooftile Coating. The vendor provided Evans Construction a 10-year warranty on the paint finish.

Homes Showcasing Painted Metal Roofs

Custom-Bilt donated its Country Manor Shake roof product for field testing at the Cavalli Hills demonstrations (Fig. 5). Evans, at the suggestion of Custom-Bilt Metals, contracted Rinkydink Builders to install the metal roofs. The color of the aluminum shakes with conventional pigments is dark brown and has solar reflectance of 0.08 and thermal emittance of 0.90. Custom-Bilt used BASF's ULTRA-Cool™ pigmented coatings to increase the shake's solar reflectance to 0.31 for the roof of the second demonstration home. Premium coil coated metal roofing probably has an excellent opportunity for applying CRCMs because 1) the metal is already painted 2) the paint coating is reasonably thick (~25 micron) and 3) the substrate has high NIR reflectance ($\rho_{NIR} \sim$ 0.55 to 0.7). The coatings for metal shingles are durable polymer materials, and many metal roof manufacturers have introduced the CRCM pigments in their complete line of painted metal roof products. The additional cost of the pigments is only about 5¢ per square foot of finished metal product (Chiovare 2002). Success of the new CRCM metal products is evident in the market share recently captured by the metal roof industry. Historically metal roofs have had a smaller share of only about 4% in the residential market. The architectural appeal, flexibility, and durability, due in part to the cool color pigments, has steadily increased the sales of painted metal roofing, and as of 2002 its sales volume had doubled since 1999 to 8% of the residential market, making it the fastest growing residential roofing product (F. W. Dodge 2002).

Homes Showcasing Asphalt Shingle Roofs

Elk Corp. donated their Weatherwood Prestique® Cool Color and their conventional Weatherwood Prestique® asphalt shingles for field testing in Redding, CA. The cool color shingle has a solar reflectance of 0.26 and a thermal emittance of 0.90. The conventional Weatherwood shingle has solar reflectance of 0.09 and thermal emittance of 0.89. The cool color shingles are advertised on Elk's web site[3] as the "first energy-efficient cool asphalt shingles offered in a palette of rich, organic colors." Elk offers a 40-year limited warranty with a limited wind warranty of up to 90 mph, and a UL Class "A" fire-rating. The prototype shingles were developed in conjunction with 3M™ to meet initial ENERGY STAR® performance levels.

[2] It's difficult to make a cool concrete tile by mixing cool pigments into gray-cement concrete, because the gray cement includes NIR-absorbing iron oxides. A white-cement concrete can be mixed with cool pigments to make a cool product. However, white cement costs about twice as much as gray cement concrete, so tiles are usually made with the latter.

[3] http://www.elkcorp.com/homeowners/products/shingles_prestique_ccs.cfm

The homes demonstrating asphalt shingles are on different cul-de-sacs but within about 100 yards of each other. Both homes have about the same azimuth orientation with respect to the sun which allows direct comparison of the thermal performance of the two roof assemblies. The residences are one-story ranch style homes built on concrete slab. Each house has about 2400 square feet of floor space, and each house uses two split system air-conditioners for comfort cooling.

Instrumentation and Data Acquisition

Instrumentation was added to each demonstration home to catalogue temperatures and heat flows across the roof and attic assembly and the relative humidity of the ambient air in the attic. Sensors were also installed in the living space to measure the indoor ambient return and supply air temperatures and indoor relative humidity. Whole house power, air-conditioner power and compressor cycling rate were measured at homes in Fair Oaks, CA. Only air-conditioner power was monitored at the Redding site.

Roof Deck and Attic Floor (Ceiling)

Heat flux transducers (HFTs) were embedded in the roof decks and the attic floor to measure the heat flows crossing the decks and attic floor of each house. The roof decks are made of 5/8-in OSB. Typical construction uses 15/32-in OSB; however, the 5/8-in OSB was selected because it is of sufficient thickness for embedding a 0.15-in thick HFT in the OSB without compromising accuracy of the heat flow (Fig. 6).

We checked the thermal conductivity of 5/8-in and ¼-in thick boards because OSB is made from various waste wood products and conductivity might vary with thickness. A 2-ft-square section of 5/8-in OSB was placed in a heat flux metering apparatus and calibrated to determine the thermal conductivity of the OSB. Top temperatures of the board were set at 7.2, 23.9, 37.8 and 48.9°C (45, 75, 100 and 120°F), which are typical temperatures observed by Parker, Sonne and Sherwin (2002) for roof decks covered by concrete tile. Results revealed that the thermal conductivity of OSB increased linearly with temperature. A thinner ¼-in OSB board was also tested and found to have thermal conductance within ± 0.5% of the measures obtained for the thicker 5/8-in board. Thermal conductivity of the thinner board varied linearly and had the same slope as the thicker 5/8-in board. The tests verified that the thinner board could be used as a cover plate to hold the heat flux transducer in place (Fig. 6), and would not adversely affect the heat flow.

Shunting due to the differences in thermal conductance of the HFT and the OSB was also accounted for by calibrating the HFT in a 2-ft by 2-ft guard of 5/8-in thick OSB using the ASTM C518 protocol (ASTM 1998). Calibration showed a slight but linear drop in sensitivity as the temperature of the OSB was increased from 4.4 to 48.9°C (40° to 120°F, at temperatures typically observed by Parker in roof decks field tested in Ft. Myers, FL).

The guard became a portion of a sandwich panel equipped with copper/constantan thermocouples and the HFT. Once calibrated the sandwich panels were shipped to the builders and installed in the adjacent roof decks of each demonstration home. The sandwich panel was made of the same material as the deck and was also the same thickness. While the roof products were being installed, the thermocouples attached to the sandwich panels were epoxy glued to the roof surface[4], taped to the topside of the deck, placed adjacent the HFT embedded in the OSB and taped to the underside of the OSB deck facing the interior of the attic. The thinner ¼-in board attaches to the underside of the deck to provide access for future maintenance (Fig. 7).

A similar procedure was used for setup of the HFT measuring the heat flow crossing the attic floor and entering the conditioned space. Here however, we taped a HFT in the center of a 2-ft by 2-ft piece of gypsum board and covered the device with R-19 batt insulation and proceeded to calibrate the transducer. In the field we simply taped the HFT to ceiling drywall and attached a thermocouple adjacent to the HFT. Later, after insulation was blown into the attic, we placed a thermocouple approximately at the top surface of the blown insulation.

Weather Station

A fully instrumented meteorological weather station was set up at Cavalli Hills to collect the ambient dry bulb temperature, the relative humidity, the wind direction and the wind speed. The station was attached to the back side on the C-style house and extended about 4 feet above the ridge vent. Pyranometers were placed on adjacent sloped roofs of all homes for measuring the morning and afternoon solar irradiance. These measures helped prove that, for instance, the west facing roofs from a pair of homes had the same intensity of solar flux. The instruments also indicated the daylight hours and displayed peak irradiance with time of day.

Power measurements

SMUD installed watt-hour transducers for measuring the cooling energy consumed by the FREUS™ air-conditioners, the whole house power and counters totaling the number of compressor starts of the air-conditioners. Whole house power transducers were checked against electrical energy measures provided by SMUD's revenue meters. Measures were checked at different points in time, and showed the transducer readings within 0.3 to 1.6% of the revenue meter readings (Table 1).

ORNL personnel also made bench top checks of the Rochester model PM 1000 transducers installed by SMUD for measuring air-conditioning power. The transducer was compared to a Wattnode transducer Model WNA-1P-240-P, which ORNL has successfully applied on several applications. Bench top tests showed the SMUD transducer (Rochester model PM 1000) read within 6% of the Wattnode transducer. Further checks of the PM-1000 transducers were made at Cavalli Hills to verify proper polarity of lead wires from each transducer, and to verify the current transducer polarity (i.e., the dot on the front of the CT points toward the house breaker). SMUD personnel conducted field calibrations of all transducers around 02/01/2005 as a check of its instruments.

[4] The painted shakes are made of thin metal of about 26 gauge and we taped the thermocouple to the underside of the shake for measuring surface temperature.

Table 1. Comparison of watt hour transducers to Cavalli Hills Revenue meter readings.						
SMUD Meters	Date		House and Address			
	From	To	4979 Mariah Place Tile Roof Standard Color Pigment kWh	4983 Mariah Place Metal Roof Standard Color Pigment kWh	4987 Mariah Place Tile Roof CRCM Pigment kWh	4991 Mariah Place Metal Roof CRCM Pigment kWh
Revenue Meter (kWh)	3/23/2005	4/19/2005	233	421	432	184
Pulse Transducer (kWh)	3/23/2005	4/19/2005	237	422	433	186
Error (%)			**1.63**	**0.32**	**0.30**	**0.98**

Data Acquisition System

Campbell Scientific micro-loggers were used for remote acquisition and recording of field data. Salient features of the micro loggers are provided in Table 2. The loggers were

Table 2. Salient Features of Campbell Scientific data loggers.

Item	Item Description	CSI Part No.
1	CR-23x Datalogger with 4 Mbytes memory	CR10X-2M
2	Array based operating system for CR-23X-4m	9801
3	Thermocouple reference thermistor for CR23X Wiring Panel	CR10XTCR
4	12 volt Power supply w/Charging regulator and rechargeable battery	PS100
5	18 volt 1.2 Amp wall charger, 6 ft.	9591
6	16-channel (4-wire) or 32-channel (2-wire) Relay Multiplexer	AM16/32
7	25-Channel Solid-State Multiplexer for Thermocouples	AM25T
8	Data cable, two peripheral connector cable for datalogger, 2 ft.	SC12
9	8-Channel Switch Closure Module	SDM-SW8A
10	Telephone Modem	COM210
11	Phone modem surge protector	6362
12	Enclosure 16/18, weather-resistant	15873

equipped with 4 Mbytes of memory, a 25 channel multiplexer for thermocouples, rechargeable battery, 115Vac-to-24Vdc transformer, modem, modem surge protector, weatherproof enclosure and associated cables.

The mirco logger was programmed to scan every 30 sec and reduce analog signals to the engineering units specified in Table C.1. (Appendix C). Averages of the reduced data were electronically written to an open file every 15-min. The averages were calculated over the 15-min interval and are not running averages; they are reset after each 15-min interval. Electronic format is comma delimited for direct access by spreadsheet programs. Data files consist of one full week of data containing 672 rows of averaged measurements representing the instrument measurements of Table C.1 written every 15-min over the 168 hours of a week. The micro logger automatically closes the existing file and opens a new data file every Friday at midnight for recording the next week of data. A dedicated desktop computer calls the micro logger and acquires the previous week of data over a modem connected to a dedicated phone line.

FIELD RESULTS

The acquisition of field data for the pair of concrete tile roofs started July 2004 while data collection for the pair of painted metal roofs began August 2004. Speculators purchased two of the four homes in Fair Oaks CA, and the two homes just happened to be one from each of the two pair of homes. Meaningful summer comparisons between homes with and without CRCM roofs did not therefore occur until the summer of 2005. We started collecting field data for the shingle roofs April 2005. Hence the discussions of field results that follow are for the summer of 2005. We intend to continue field acquisition through the summer of 2006 and include any additional insight gained from the field demonstrations in future refereed journal articles.

The attics and roof decks of each demonstration home were instrumented to document the immediate effects of CRCMs on the deck and attic air temperatures and the heat flows crossing the roof deck. Our intent was to demonstrate typical summer performance of CRCMs and to also collect data useful for formulating and validating computer codes capable of calculating the heat transfer occurring within the attic. Once validated, these attic simulations can be coupled to whole house building models for simulating and predicting local, state and national energy savings afforded by roofs with CRCMs.

The results that follow describe temperature and heat flow results for the roofs and attics of the demonstration homes. Afterwards, discussions about the cooling energy and whole house power measures are presented in the section on Cooling Energy Savings.

Concrete Tile Roofs

As stated earlier, the Cool Tile IR COATING™ increased the solar reflectance of the medium profile concrete tile from 0.10 to 0.41. The boost in solar reflectance dropped the surface temperature of the CRCM tiles consistently below those with conventional color pigments. During the afternoon hours for a week in September (Figure 8) the ambient air temperature daily peaked around 30 to 32°C (86 to 90°F). The ridge vent for the tile roofs ran north and south and during the afternoon the sun's irradiance is directly incident on the west facing roof. Surface temperatures of the tile roofs with CRCMs are about 5 to 7.5°C (9 to 13.5°F) cooler during peak irradiance than the conventional pigmented color tile. Similar reductions occur in the attic air temperature, which is about 4°C (7.2°F) cooler than the attic air for the home with conventional pigmented tile. The peak surface temperatures are observed around 3:30 p.m. while the attic air temperature peaks about 1½ hours later at about 5 p.m. P.D.T. (Figure 8), which occurs at about the same time as the peak in outdoor air temperature.

Further inspection of the heat crossing the roof deck and the attic floor reveals 1) that the CRCMs reduce the amount of solar heat penetrating through the deck and the attic floor, and 2) that the peak heat flow crossing the attic floor is delayed similar to the trends in peak attic air temperature and therefore reflects trends that may benefit peak demand reductions for utilities.

About a 25% drop in deck heat flow occurs during times of peak irradiance because of the higher solar reflectance of the tile with CRCMs. An averaged 20% reduction was calculated for daytime[5] exposure during the full month of September. The corresponding drop in heat flow penetrating through the attic floor and into the conditioned space was about 10% of that penetrating the attic floor of the home with conventional color tile (Figure 9). It is important to note that the medium profile tiles were installed on battens and sub-tile venting occurs over the batten and below the tiles. Miller et al. (2005) showed sub-tile venting to further reduce the heat flows crossing the roof deck.

[5] Daytime was defined as the time when the pyranometer measurements on the west facing roof exceeded 250 Watts per square meter, which corresponds to about 10 a.m. through 6:30 p.m.

We observed the heat flow entering the attic floor of the home with CRCM tile as being less than the heat flow in the other home from about noon to well past 8 p.m. The attic floor has code level R-19 blown insulation and the combination of attic insulation, sub-tile venting and thermal mass of the conventional tile most likely caused the continued benefits into the evening hours. The time dependent valuation of energy places a premium on electricity usage from about 1 to 6 p.m. The trends shown for the pair of tile roofs therefore reflect even better potential economic benefits because less air-conditioner power is consumed during the utilities peak summer time demands.

Painted Metal Roofs

The two C-style homes with painted metal roofs are oriented with their respective ridge vents running east-west. Therefore the south facing roofs of each home received both morning and afternoon direct solar irradiance with little or no shading throughout the day (Figure 5). At solar noon for a day of clear skies in September 2005, the painted metal roof with CRCMs had peak surface temperatures that were 10°C (18°F) cooler than the metal roof with conventional paint pigments (Fig. 10). The peak attic air temperature for the home with CRCM metal shakes was 5°C (9°F) cooler (Fig. 10). The drop in surface temperature in turn reduced the heat penetrating into the attic as measured by the heat flux transducer embedded in the OSB decking of the south-facing roof (Fig. 11). Results depict a consistent and sustained reduction in heat flow during the daylight hours. Integrating the heat flow crossing the roof deck for the full month of September showed that the painted metal roof with cool pigments had 32% less heat flow than the deck having the same color painted metal roof but with conventional paint pigments.

CRCMs appeared to provide more thermal benefit for the pair of homes with metal roofs then the pair of homes with tile roofs. We believe the difference is attributable to sub-tile venting of the concrete tile roofs as compared to the metal shake roofs which were direct nailed to the roof deck. Sub-tile venting is more efficient on hotter roofs so it diminishes the effect of the solar reflectance of the cool tiles.

Asphalt Shingle Roofs

July and August ambient air temperatures in Redding, CA often exceed 45°C (110°F). Field data for August 2005 show the conventional shingles exposed in Redding had peak temperatures of about 73°C (163°F) as compared to peak temperatures of about 70°C (158°F) for the shingle with CRCMs. The difference in surface temperature between the conventional and CRCM shingle is not as large as the differences observed for painted metal and or concrete tile simply because the CRCM shingle increased solar reflectance by only 0.17. However, reducing the temperature of shingles has potential benefits for improving the chemical and flexural properties of the shingles. Terrenzio et al. (2002) showed that heating of asphalt shingles promotes the vaporization and diffusion of oils from the asphalt with the subsequent migration of oxygen into the asphalt. Terrenzio noted that as aging progresses, the stiffness of the asphalt increases. Therefore CRCMs may indeed increase the service life of shingles.

Heat flow penetrating the west-facing roof for the pair of homes with asphalt shingles again showed similar trends to the tile and painted metal demonstrations. The deck heat flow is consistently lower when CRCMs are applied to the shingles (Fig. 13). Roughly a 30% drop as compared to the conventionally pigmented shingle was observed over the daylight hours during a week in August 2005.

COOLING ENERGY SAVINGS

Occupancy habits are the Achilles heel of any residential demonstration. It is ironic that while the research conducted in building science targets improved energy efficiency and quality of life, the habits of people often deter energy conserving practices. Testing the homes while unoccupied would certainly help document reductions of whole house energy. As example, Parker et al. (2002) demonstrated that an unoccupied Florida home with a “white reflective” barrel-shaped concrete tile roof reduced the annual cooling energy by 22% of the energy consumed by an identical and adjacent home having an asphalt shingle roof. The cost savings due to the reduced use of comfort cooling energy was about US $120 or about 6.7¢ per square foot per year. Parker’s results have become a benchmark in the area of building science. However, Parker’s results beg the question. “Are the results realistic when one considers people’s occupancy habits?”

The principal focus for the field demonstrations centered on collecting attic and roof data to prove the thermal benefits of the cool pigment technology. But the experiments also included power measurements as well as air-conditioning supply and return air temperatures in an effort to deduce estimates of annual savings despite the effects of occupancy habits or, put differently, corrected for the effects of occupants.

The Sacramento Municipal Utility District (SMUD) forwarded the 2005 summer revenue meter readings for the two pair of demonstration homes in Fair Oaks, CA (Table 3). The kWh use during the 2005 summer for the home with cool color metal shakes was

Table 3. Monthly Energy from Revenue Meter Readings for Demonstration Homes in Fair Oaks CA

	Whole House Monthly Energy (kWh)		Whole House Monthly Energy (kWh)	
Month Ending	Metal Shake Conventional Color	Metal Shake Cool Color	Medium-Profile Tile Conventional Color	Medium-Profile Tile Cool Color
6/18/05	409	552	734	993
7/20/05	1433	749	891	1511
8/18/05	1034	807	884	1412

26% less than that for the same home with conventional metal shakes. However, the cool tile used 56% more energy than did the home with standard tile. Solar reflectance of the cool tile is about 0.41 as compared to 0.08 for the same conventional color tile and should therefore demonstrate some energy savings. Further review of the data and personal discussions with the homeowners revealed that the resident in the home with standard tile roof did not keep the thermostat at 22.2°C (72°F) until after August 19, 2005. The resident is a medical student who spends more time in class and at work than at home. In contrast, the residents in the home with a cool color concrete tile roof utilize their home’s amenities more so than their neighbor. We also found out that they dropped the thermostat setting from 22.2° to 21.1°C (72° to 70°F) at night simply for their own sleeping comfort, while the medical student simply crashed in bed.

To correct for these differences in life style, power measurements were reduced into daily electrical energy consumptions. The electrical usage of the whole house and the air-conditioner were plotted against the daily average outdoor air-to-indoor air temperature difference (labeled as OD air-to-Return air in figures 14 - 18). Regression analysis of the reduced data helped to mask the effects of different thermostat settings and occupancy habits. Results for the concrete tile, painted metal and asphalt shingle demonstrations follow.

Cool Concrete Tile Roof

Linear regression of daytime electrical usage against the daytime average outdoor air-to-indoor air temperature difference for both homes with concrete tile roofs shows the home with CRCM concrete tile used more electrical energy than the home with conventional pigmented color tile (view red regression line in Fig. 14). Similar results were also observed in Table 3 from SMUD's revenue meter readings. As stated the one resident hardly lived at home while the other homeowner maintained a more normal lifestyle. Therefore occupancy habits caused the discrepancy and an occupancy habit correction (OHC) is needed. The home with CRCM tile is saving energy but at a different base of comparison than the home with conventional color tile because of miscellaneous plug loads (i.e., lights, electrical cooking, water-pumps in Jacuzzi, etc.).

The field data was searched over the two years of measurements for periods requiring no comfort cooling in hopes of determining miscellaneous plug loads consumed by the resident in the home with the CRCM tile roof. Ample data was found for periods in the early spring and the late fall. The whole house electrical energy use for these days having no compressor energy was compared to the other home and found to use an averaged 12 kWh per day more plug load. We then subtracted 12 kWh from the whole house electrical energy used by the home with CRCM tile to better compare to the whole house usage of the other home (blue regression line in Fig 14). We also plotted the air-conditioner draw again against the daily average outdoor air-to-indoor air temperature difference for both homes (Fig. 15). As the outdoor air-to-indoor air temperature difference increased, the savings in consumed cooling energy also increased (cyan line in Fig. 15). The savings in cooling energy range from about 1 to 2 kWh per day[6], and yield an energy savings of about 9% of the whole house electrical energy consumed per day by the home with conventional pigmented tile (black regression line Fig. 14).

Cool Painted Metal Roof

Linear regressions were again generated for the daily whole house electrical energy and air-conditioning energy consumed as functions of the daily average outdoor air-to-indoor air temperature difference for both homes with painted metal roofing. Recall that the revenue meter readings for the pair of homes with painted metal roofs indicated the home with CRCMs used 26% less electrical energy than the home with a conventional pigmented metal roof. Here we believe occupancy habits skewed the data to favor energy savings. Savings are about 8 kWh of electricity per day (Fig.16); however, air-conditioner usage indicates savings of about 2 kWh per day[7] (Fig. 17). We therefore believe savings are similar to those for the tile roofs and are about 8 to 10% compared to the home having a conventional pigmented metal roof of the same color.

Cool Asphalt Shingle Roof

The electrical energy measured for the air-conditioners operating in demonstration homes in Redding CA (Fig. 18) are more than twice the energy measured for the two pair of homes in Fair Oaks CA. The demonstrations in Redding used two 3½ -ton A/C units, while in Fair Oaks only

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[6] Savings do not include the electrical energy used by the indoor blower which pulls about 700 W. Further analysis will include these savings as reflected in reduced compressor on-time for the homes with CRCM roofs.

[7] Savings do not include the power of the indoor blower which consumes about 700 W. Further analysis will include these savings as reflected in reduced compressor on-time for the homes with CRCM roofs.

one 3-ton FREUS™ air-conditioner was needed to provide comfort cooling. Also the homes in Redding were stick-built ranch style homes with 2400 square feet of floor space while the homes in Fair Oaks are two-story homes with 1400 or 1600 square feet of floor space and they also have R-16 ICF walls (see section on Demonstration Home).

When the outdoor air and return air temperatures are about the same, the regression lines for the pair of homes nearly intersect (Fig. 18). This simply means that no cooling is required by the homes, and there is no compressor electrical usage. However, as the temperature difference from the outdoor air to the home's return air increases, the cooling savings also increase for the pair of shingle demonstrations (Fig. 18). At an outdoor air-to-indoor air temperature difference of 10°C (18°F) [about 32.2°C (90°F) outdoor air temperature] the home with CRCM asphalt shingles uses 6.3 kWh per day less electricity[8] than the other home with conventional shingles. The cool pigments are therefore providing savings of roughly 0.90 kWh per day per ton of cooling capacity. The whole house electrical consumption for the homes was gleaned from Redding Electric, and over the summer months (June through September) the revenue meter for the standard home averages to about 55 kWh per day. Therefore, whole house power drops about 11.4% due to the use of CRCMs in asphalt shingles. It is interesting that the hotter the outdoor air temperature the greater are the energy savings for the air-conditioners operating in the homes with CRCM roofs. The trend is slight yet could be important in terms of Time Dependent Valuation of energy that places a premium cost on energy consumed during the hottest portion of the day.

Again it is important to note that revenue meter readings from Redding Electric do not show positive energy saving benefits because of occupancy habits. The one home with a standard shingle roof consumed 1705 kWh from June through September 2005 by revenue meter data from Redding Electric. In comparison, the home with CRCM shingles used 2845 kWh (67% more energy) over the same time period. Occupants in the home with conventional shingles maintained a different lifestyle as compared to the occupants in the home with CRCM shingles.

BENEFICIAL RESULTS OF SHOWCASE HOMES

The field demonstrations turned out to be a powerful way for the tile, metal and asphalt shingle industry participants to showcase and market the performance of new CRCMs to consumers, developers, designers, and roofing contractors. For example, cool nonwhite CRCM coatings have been enthusiastically adopted by premium coil coaters and metal roofing manufacturers. BASF Industrial Coatings launched "ULTRA-Cool™," a line of Kynar coatings that quickly replaced the more conventional silicone modified polyester coatings. Coil-coater Steelscape recently introduced Spectrascape MBM, a cool Kynar coating for the metal building industry. A third industrial partner, Custom-Bilt, switched over 250 of its metal roofing products to cool colors. Tony Chiovare, CEO of Custom-Bilt Metals, stated that the additional cost of the cool-pigments is only about 5¢ per square foot of finished product (Chiovare 2002), which researchers have shown will pay for itself easily within three years because of the building energy savings (Miller et al. 2004).

The new asphalt shingles showcased in Redding have resulted in the demonstrable reduction of heat build up in the roof deck through the use of cool pigments. John McCaskill, Product

[8] Savings do not include the electrical energy used by the indoor blower which pulls about 700 W. Further analysis will include these savings as reflected in reduced compressor on-time for the homes with CRCM roofs

Brand Manager for Elk Corporation, reports the additional finished product cost is roughly 25¢ per square foot which makes this product a reasonable alternative to radiant barriers for the reduction of cooling load. The combined cost effective nature of cool colored asphalt shingles with the potential reduction of Urban Heat Island effects provides a mainstream solution for the residential re-roof market as well as new construction. Elk now offers 4 cool shingle colors across two product lines.

CONCLUSIONS

Thermal performance data proved the superior performance of CRCM in concrete tile, painted metal and asphalt shingle roof products. Surface temperatures are cooler causing average heat flows through the roof deck to drop by 20% for cool pigmented tile, by 32% for cool pigmented painted metal shakes and by 30% for cool pigmented asphalt shingle roofs as compared to conventional roofs. This in turn drops the heat penetrating into the conditioned space which results in cooling and whole house energy savings. Cool pigmented tile and cool pigmented metal shakes reduced whole house electrical energy by about 10%. The asphalt shingle demonstration showed higher savings at about 13%, which we attribute to the difference in construction of the Fair Oaks homes with ICF walls and the Redding homes with conventional 2 by 4 walls. The energy efficient homes with ICF walls in Fair Oaks are providing savings of about 0.67 kWh per day of electrical energy per ton of air-conditioning capacity while in Redding about 0.90 kWh per day is saved per ton of air conditioning capacity.

California's ability to meet peak electricity demand in the future is one of the primary electrical issues confronting its public utility companies. The CEC has stated that hot summer temperatures can drive up peak electrical demand as much as forty-five percent, and California is increasingly relying on out-of-state electrical supplies. Residential air-conditioning loads represent almost 14 percent of the summer peak demand; the equivalent of over 7,000 MW of peak capacity during a hot California summer day. To exacerbate the problem, significant new housing growth in both the near and long term will occur in California's urban areas and hot inland regions. "Cool Roofs" can provide a part (roughly 10%) of the solution to California's dilemma without introducing new complexity (no moving parts). The market opportunity therefore exists for a "cool roofs" business venture. What is needed is the reasoned faith derived from the research and the fortitude to act upon the results.

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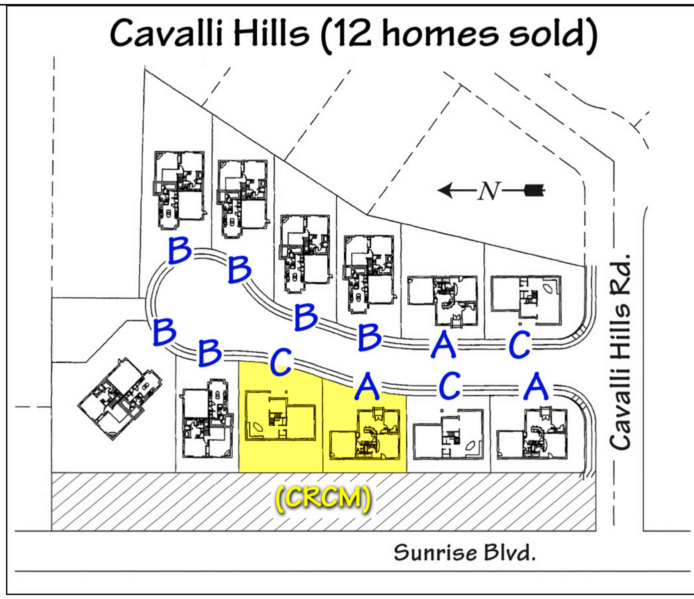

Figure 1. Plan view showing orientation of the demonstration homes in Fair Oaks, CA. The roofs of the A-style homes are Hanson's Hacienda medium profile concrete tile; roofs of the C-style homes are Custom-Bilt Metals Country Manor Shake. All roofs have the same dark brown color.

Figure 2. Hanson's concrete tile loaded onto the roof of one of two A-style homes. The tiles were offset mounted from the roof deck using 1 in by 1 in battens.

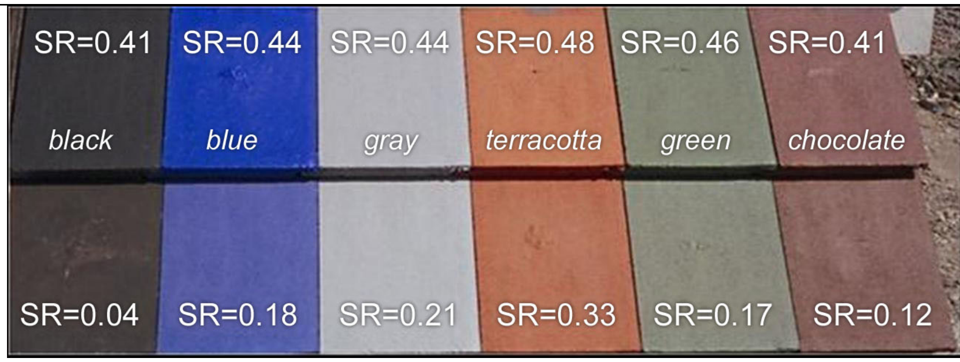

Figure 3. Solar reflectance of concrete tile roofs with CRCMs (top row) and without CRCMs (bottom row). The COOLTILE IR COATING™ technology was developed by Joe Reilly of American Rooftile Coatings.

Figure 4. Finished A-style home demonstrating Hanson Hacienda concrete tile after retrofit painting by American Rooftile Coatings.

Figure 5. Finished C-style home demonstrating Custom-Bilt Metal's painted metal shake having ULTRA-Cool™ pigmented coatings by BASF.

Figure 6. Heat flux transducer embedded in an OSB guard and used to measure heat flow crossing the roof decks of the demonstration homes.

Figure 7. Instrumented sandwich panels contain thermocouples and heat flux transducer for measuring roof temperatures and heat flows.

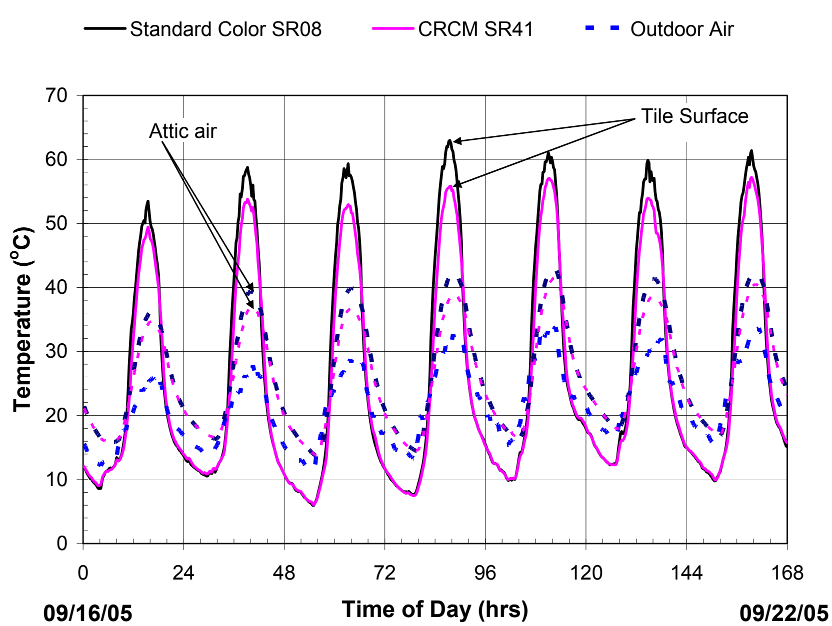

Figure 8. Surface and attic air temperatures for the pair of concrete tile roofs with and without CRCMs for a week of September 2005 data.

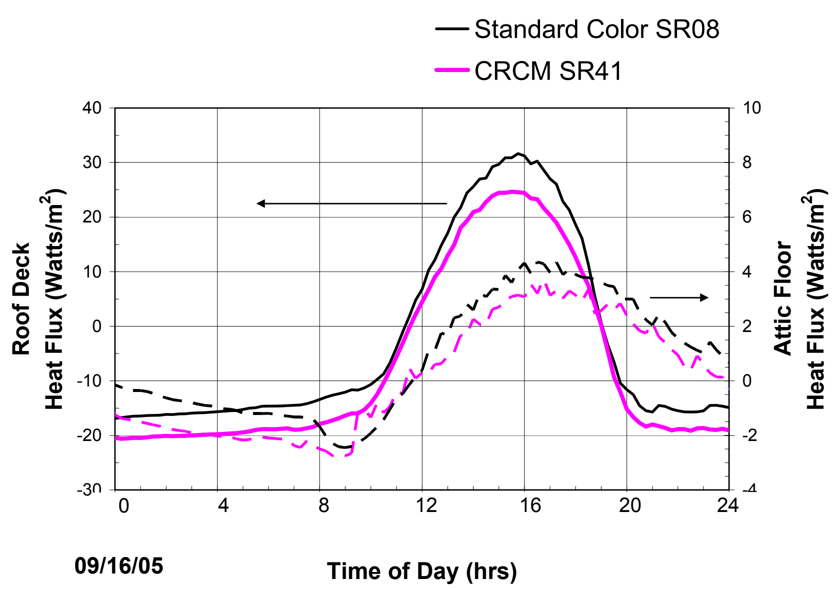

Figure 9. Heat flows penetrating the roof deck and attic floor of the pair of homes with concrete tile roofs with and without CRCMs.

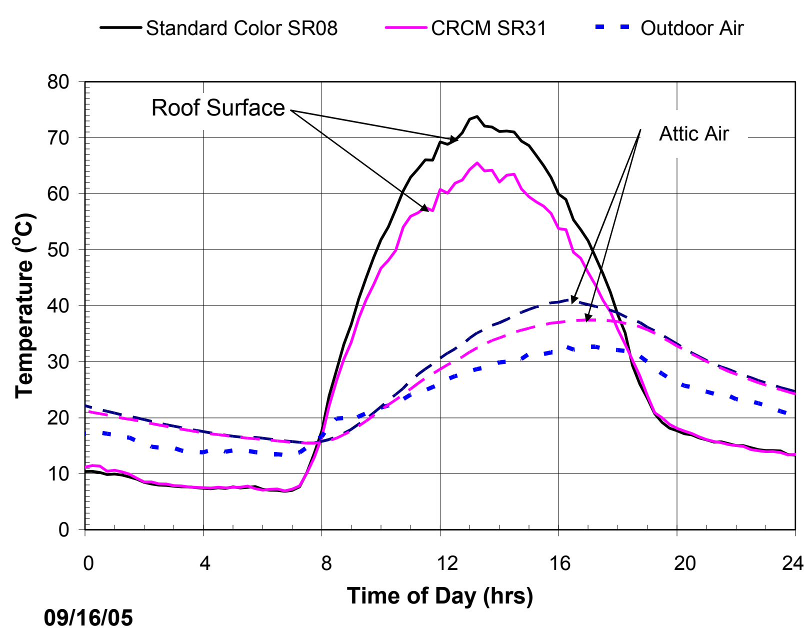

Figure 10. Surface and attic air temperatures for the pair of painted metal shake roofs with and without CRCMs for a week of September 2005 data.

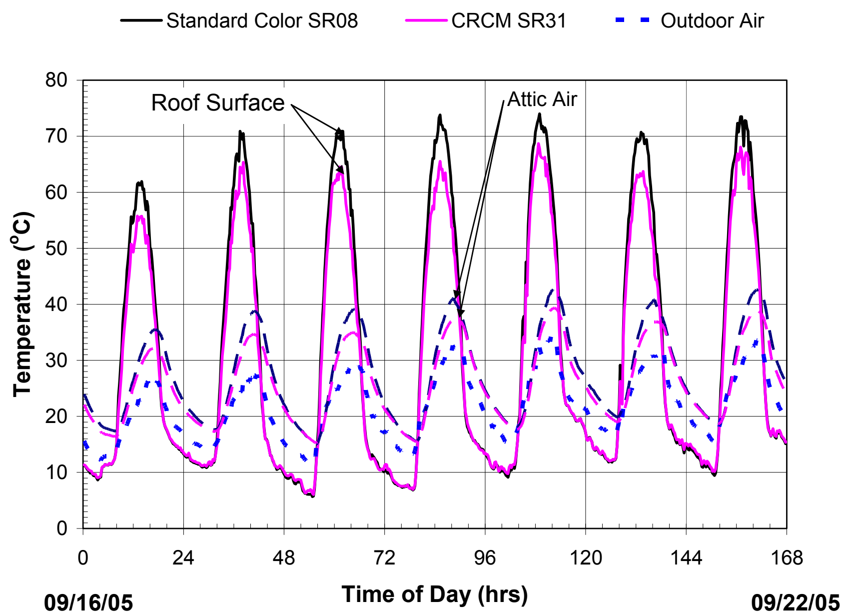

Figure 11 Heat flows penetrating the roof deck for the pair of homes with painted metal shake roofs with and without CRCMs.

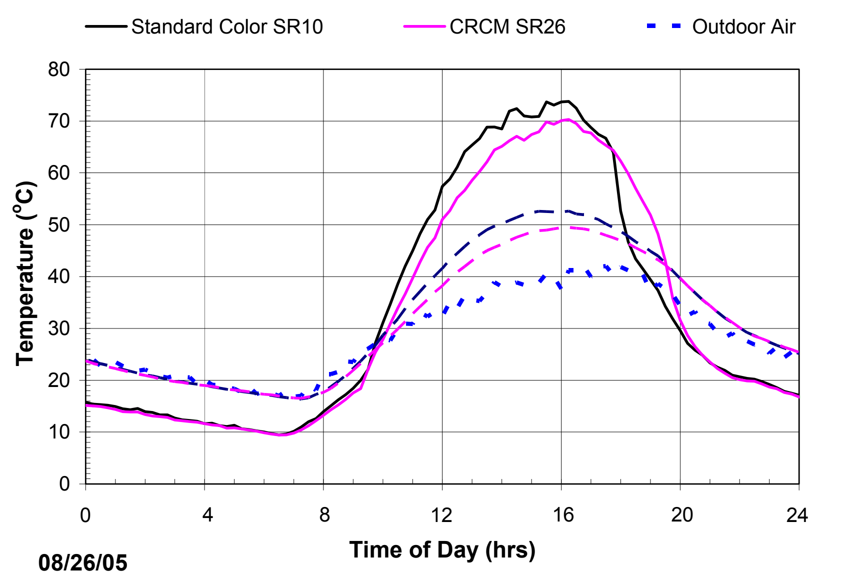

Figure 12. Surface and attic air temperatures for the pair of asphalt shingle roofs with and without CRCMs for a week of August 2005 data.

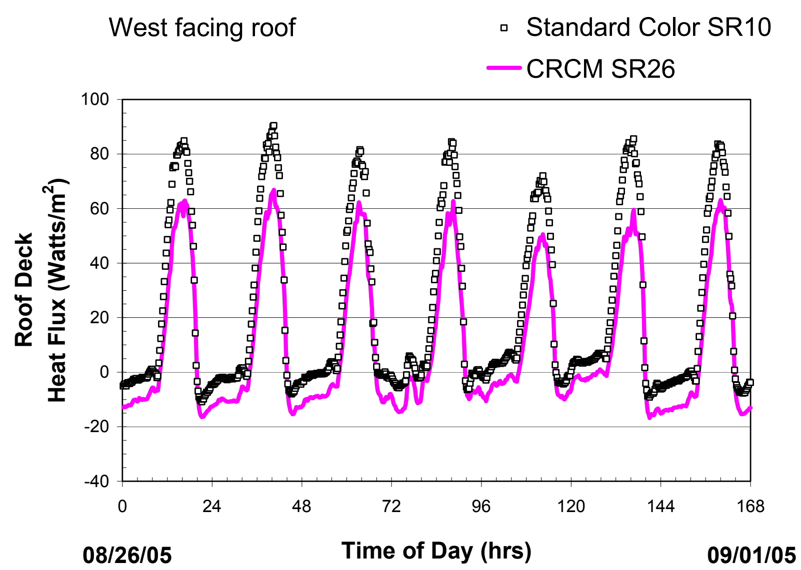

Figure 13 Heat flows penetrating the roof deck for the pair of homes with asphalt shingle roofs with and without CRCMs.

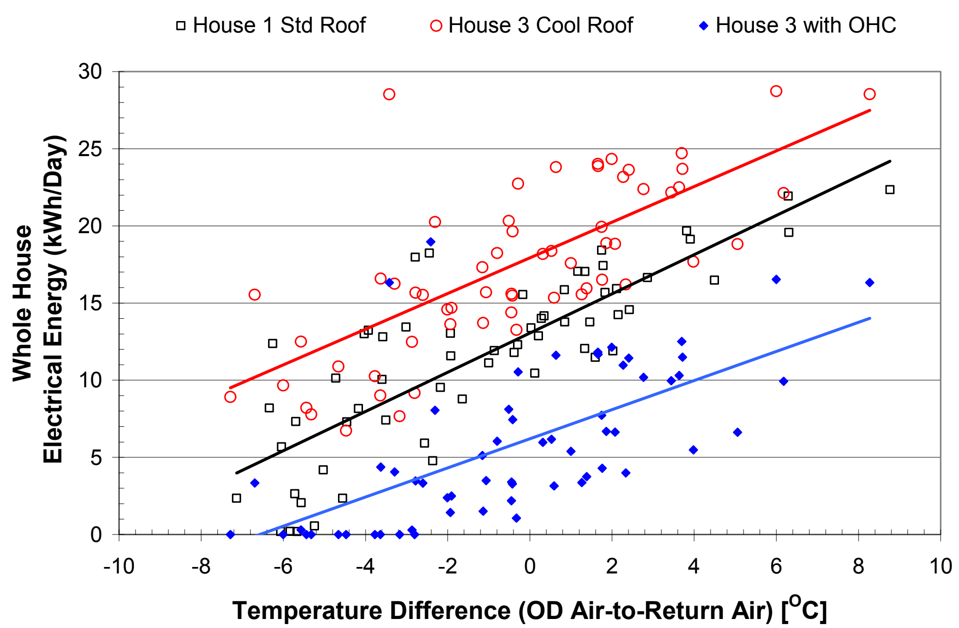

Figure 14. The whole house energy savings, measured during the daylight hours (May through July 2005), for demonstrations with concrete tile roofs with and without CRCMs.

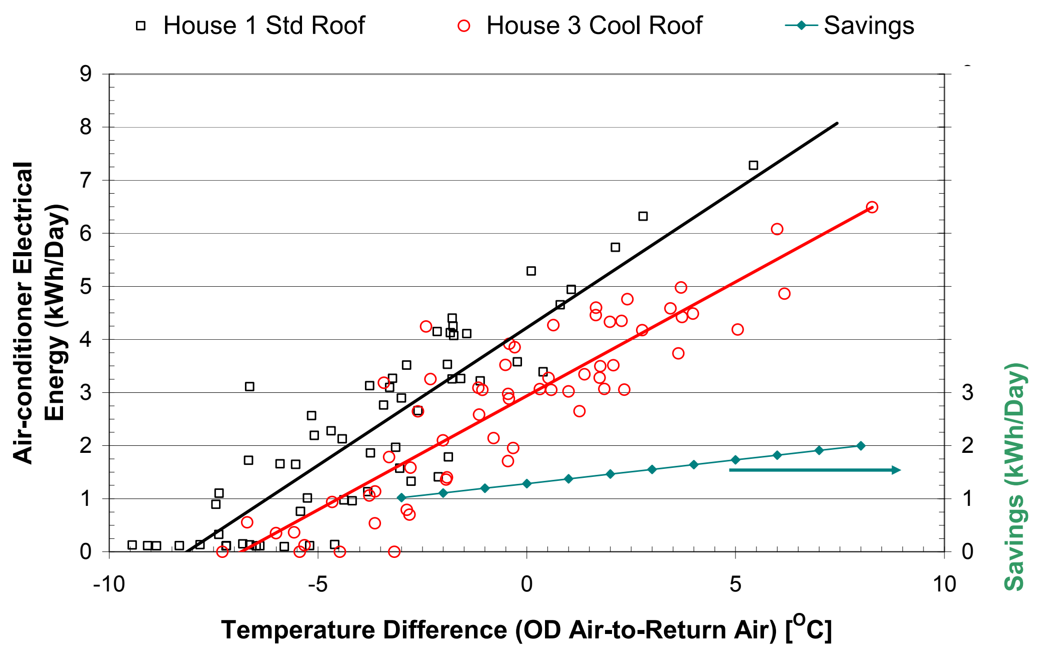

Figure 15. Air-conditioning cooling energy savings, measured during the daylight hours(May through July 2005), for demonstrations with concrete tile roofs with and without CRCMs.

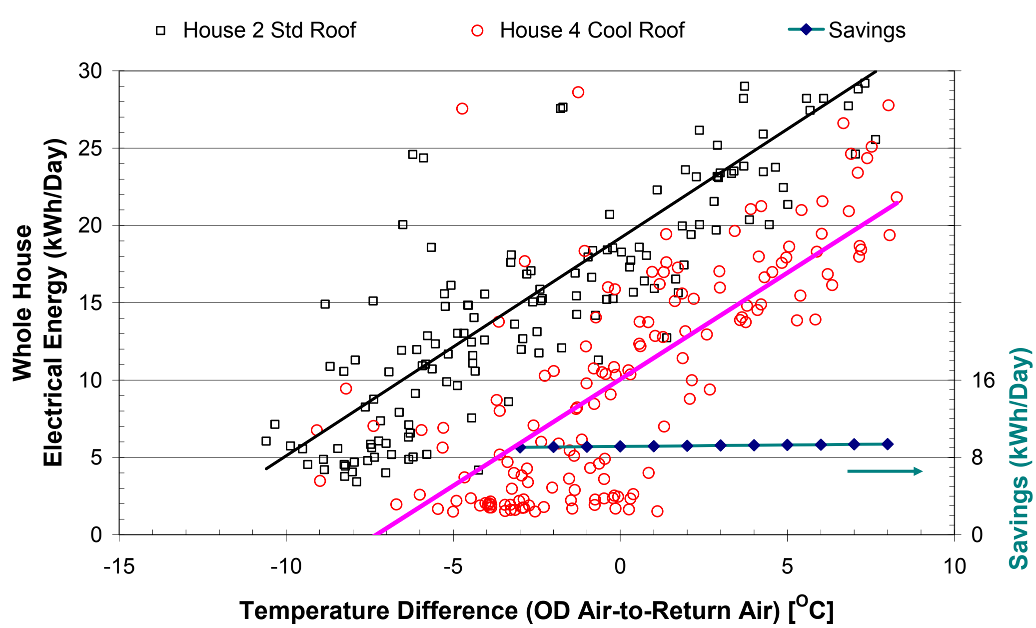

Figure 16. Whole house energy measured during the daylight hours (May through July 2005), for demonstrations with painted metal roof shakes with and without CRCMs.

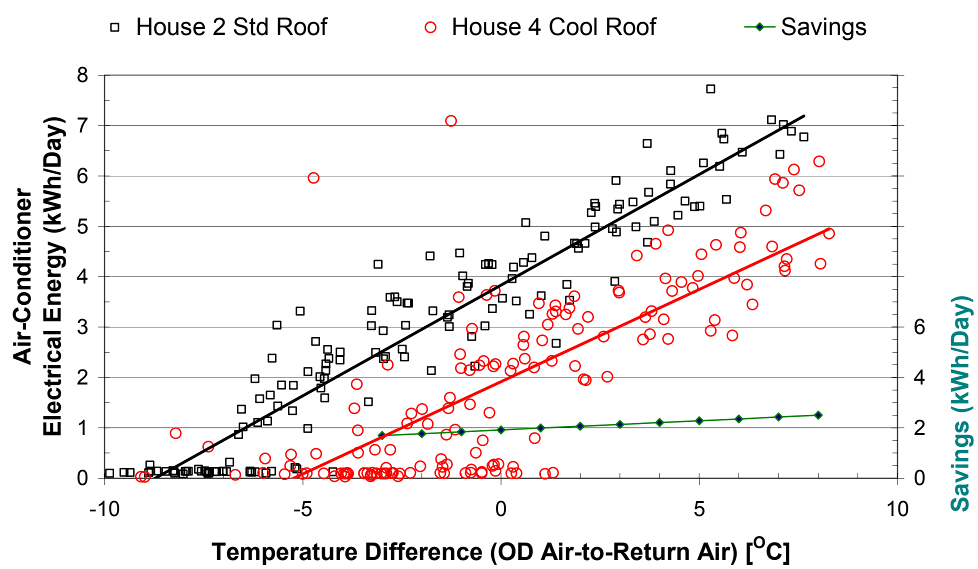

Figure 17. Air-conditioning cooling energy savings, measured during the daylight hours (May through July 2005), for demonstrations with painted metal roof shakes with and without CRCMs.

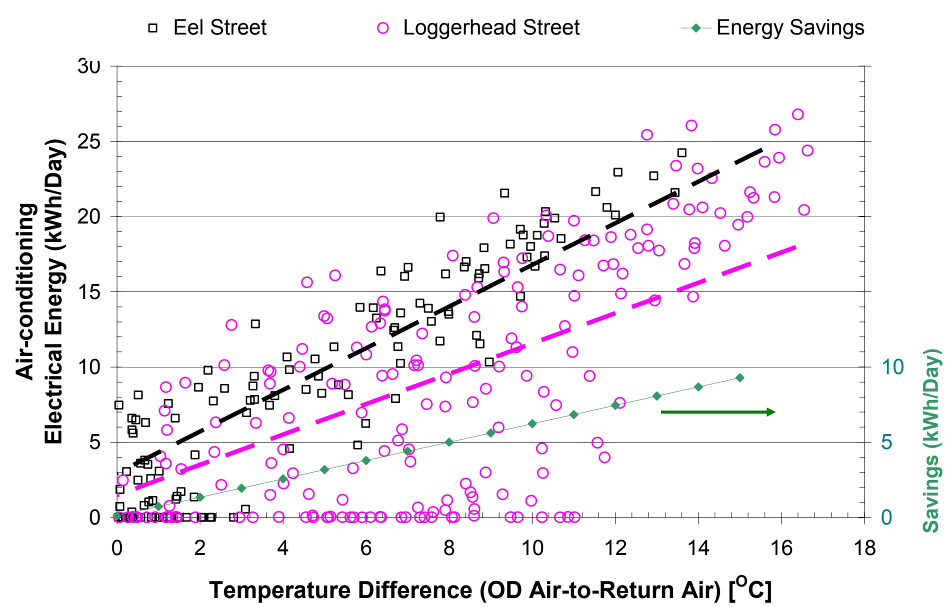

Figure 18. Air-conditioning cooling energy savings, measured during the daylight hours (May through July 2005), for demonstrations with asphalt shingle roofs with and without CRCMs.

MEMORANDUM OF UNDERSTANDING

HOMES IN SACRAMENTO, CA SUBDIVISION FOR DEMONSTRATING CRCM ROOFS AND ICF WALLS

Appendix A

This Memorandum of Understanding represents an agreement by Oak Ridge National Laboratory (ORNL), the Sacramento Municipal Utility District (SMUD) and Mike Evans Construction to cooperate in the development and testing of cool roof colored materials (CRCM).

Whereas, the California Energy Commission (CEC) has contracted the Lawrence Berkeley National Laboratory (LBNL) and the Oak Ridge National Laboratory (ORNL) to develop cool roof colored materials (CRCM) that are visibly dark but can reflect light like a "white" roof in the infrared portion of the solar energy spectrum.

Whereas, LBNL and ORNL are working with the tile, metal and asphalt-shingle roofing industries to accomplish the CEC goal of making CRCM a market reality for all residential roof products within the next five years.

Whereas, the CEC's objectives are 1) to offer consumers information that promotes the development and increased use of highly reflective CRCM and 2) to develop colored composition shingles with solar reflectance of at least 35% and tile and metal materials with reflectance of 50% or more.

Whereas, the Buildings Technology Center (BTC) of the ORNL intends, with support from the Sacramento Municipal Utility District (SMUD) and the cooperation of Mike Evans Construction to set up in March 2003 four residential demonstrations consisting of two pairs of single-family detached homes that have roofs of cool tile (supplied by Hanson Roof Tile) and painted metal materials (supplied by Custom-Bilt Metals) and about March 2004 two additional roofs with composition shingles once CRCM are developed for field-testing.

Whereas, SMUD's Customer Advanced Technologies program is helping subsidize Evans Construction in exchange for acquiring thermal performance data of insulated concrete form (ICF) walls.

Whereas, it makes good sense to combine the efforts of the parties and work together to measure and document wall, roof and building performance for the 6 demonstration houses. We will instrument four homes during construction slated for March 2003, and will monitor the homes over a three-year period ending about March 2006. The two additional homes with composition shingles are contingent on the development of CRCM shingles.

Whereas, Table 1 lists all the instrument measurements currently proposed by ORNL and SMUD.

Therefore, the parties agree to undertake the activities described below or otherwise agreed in writing during the course of the demonstration project:

DEMONSTRATION HOMES

1. **Evans Construction** will make four demonstration houses available in 2003, and will make available two homes about March 2004 for the activities described below.

INSTRUMENTATION FOR EACH HOME

2. **ORNL** personnel shall make 4-ft by 4-ft sandwich test panels of the same material as used for the roof decks at the demonstration homes, probably oriented strand board (OSB). Each sandwich panel will be made of two sections equaling the same thickness as the rest of the deck. The two panels will sandwich thermocouples and a heat flux transducer for measuring thermal performance of the roofs. A spare thermocouple will be included for possibly measuring the surface temperature of the tile and metal roofs.

3. **Evans Construction** will notify ORNL of the start date for constructing the roof decks, and **ORNL** shall ship eight sandwich test panels to Evans Construction prior to the specified start date.

4. **ORNL** will contract **Dynamic Roofing** (or other firm specified by Evans Construction) to install the sandwich test panels as part of the deck for the test roofs. The north-south orientation of the homes makes it necessary to use two panels per house. The roofing contractor will center and attach one panel to the west-facing roof and center and attach the other to the east-facing roof.

5. **ORNL** personnel under the supervision of **Mike Evans Construction** shall instrument the attic for measuring the attic air temperature and relative humidity and the temperatures around the ceiling insulation as well as the ceiling heat flux. A temperature and relative humidity probe will be mounted in the return duct to measure the return air temperature and relative humidity from the house (see Table 1 for a listing of measurements).

6. **SMUD** will install two watt-hour meters and meter bases per house. One meter will measure total power consumption; the other will measure the power draw of the HVAC unit. The meters shall be configured with a pulse output device.

7. **SMUD** will run instrument wires from the two watt-hour meters to the DAS.

8. **SMUD** in conjunction with ORNL personnel will program the meters for the appropriate watt-hour pulse ratio. SMUD shall have the appropriate hardware and software to program the meters such as the Smartcoupler and MeterMate software used for the GE form 2S kWh-demand kV meter.

9. **ORNL** personnel shall install a pyranometer and an anamometer on the west facing and on the east facing roofs of each house in the vicinity of the heat flux transducers. The instruments have about a 3-in diameter and stand about 2-in off the roof. Instrument wires will be run down the roof and along the soffit to a data acquisition system (DAS).

DATA ACQUISITION SYSTEM

10. **ORNL** personnel under the supervision of Mike Evans Construction shall install a data acquisition system in each house and shall make all instrument connections to the DAS. The DAS can be placed in the attic, and shall have an extended temperature calibration range from -55°C to 85°C for possible attic placement. However, problems do occur even with the best DAS and placement in the garage or on an exterior wall behind the house would cause the least hassle for the technician and the least intrusion for the homeowner.

We will use a Campbell Scientific Model CR23X-4M micro-logger with model AM25T multiplexer for expanded channel capability. The DAS shall be in a NEMA 4 weatherproof and lockable enclosure. The DAS shall have 4 megabytes of extended memory, a phone modem, modem surge protector and rechargeable battery.

11. **ORNL** shall fully program the DAS and shall fully document the data acquisition code for use in later trouble shooting problems by ORNL, LBNL or SMUD personnel. Once operable, ORNL will forward the documentation to LBNL and SMUD.

12. **SMUD** will direct the phone service to run independent phone lines for hook up to each DAS for transmitting data by modem. These lines will be completely independent of the homeowner's phone system, and shall remain intact for the 3-year field demonstration.

13. **SMUD** will be responsible for conducting routine maintenance of the DAS systems, and shall support ORNL by trouble-shooting and making operable the DAS.

14. **ORNL** shall weekly check the data string output by the DAS received over the modem, and shall request **SMUD** to make appropriate corrections to reestablish power, reconnect phone lines or replace backup battery or the backup battery power supply. However, ORNL shall take responsibility for damage to the DAS and instruments, and will either reimburse **SMUD** for replacement of damaged equipment or ORNL will themselves make appropriate repairs with exception of the watt-hour meters.

AIR TIGHTNESS OF HOUSES

15. **ORNL** personnel under the coordination of Mike Evans Construction shall measure the air tightness of the demonstration homes using a Minneapolis Blower Door test apparatus. A Duct Blaster™ apparatus will be used to check the tightness of the air duct system. Both outside air infiltration and duct leakage will affect air conditioning performance, therefore we will attempt to make all homes about the same tightness. The air tightness of the house and ducting shall be checked after Evans has completed construction but before the homeowner occupies the homes.

16. **ONRL** also requests the opportunity to conduct the air tightness testing at conclusion of the three-year study, and will coordinate the testing with the homeowner.

ONSITE REFLECTANCE MEASURES

17. **ORNL** or **LBNL** personnel will visit the sites quarterly the first year and then semi-annually to measure the reflectance and emittance of the test roofs. The measures will require personnel to climb up a ladder to the roof and make the measurement, which will take only about 15 minutes.

THERMAL SCANS OF HOUSES

18. **ORNL** personnel request the opportunity to make thermal scans of the homes to judge the relative effectiveness of the roofing systems once the homes are built and occupied. As the roof systems age the thermal scans will help document the overall thermal performance of the roof as compared to their starting performance. The scans are taken outside the home and will be conducted yearly.

VISITATION

19. In case of maintenance, repair, routine checks etc, **ORNL** and **SMUD** personnel will coordinate through Evans Construction or the homeowners the permission to egress said property. The homeowners shall allow visitation privileges to ORNL, LBNL or SMUD. However personnel shall schedule visits amenable with the homeowner prior to the actual visit. Visits will be limited to routine maintenance checks and if necessary unscheduled checks to trouble-shoot instruments and or the DAS.

20. At completion of the three-year study **ORNL** will remove the DAS, instruments and wires with exception of those embedded in the roof deck.

CONTACTS

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MEMORANDUM OF UNDERSTANDING

DEMONSTRATION OF STANDARD PRODUCTION ASPHALT SHINGLES AND ADVANCED SHINGLES HAVING COOL ROOF COLOR MATERIALS ON HOMES IN REDDING, CA

Appendix B

This Memorandum of Understanding represents an agreement by Oak Ridge National Laboratory (ORNL), the Elk Corporation and *Ochoa and Shehan Inc, a residential construction firm in Redding, CA* to cooperate in the field testing and demonstration of cool roof colored materials (CRCM).

Whereas, the California Energy Commission (CEC) has contracted the Lawrence Berkeley National Laboratory (LBNL) and the Oak Ridge National Laboratory (ORNL) to develop cool roof colored materials (CRCM) that are visibly dark but can reflect light like a “white” roof in the infrared portion of the solar energy spectrum.

LBNL and ORNL are working with the tile, metal and asphalt-shingle roofing industries to accomplish the CEC goal of making CRCM a market reality for all residential roof products within the next five years.

Whereas, the CEC’s objectives are 1) to offer consumers information that promotes the development and increased use of highly reflective CRCM and 2) to develop colored composition shingles with solar reflectance of at least 25% and tile and metal materials with reflectance of 50% or more.

Whereas, the Building Envelope Group of the ORNL intends, with support from the Elk Corp. and the cooperation of *Ochoa and Shehan* Construction to set up and monitor for two years (starting Jan 1, 2005 and ending Dec 31, 2006) two residential demonstrations consisting of a pair of single-family detached homes that have composition shingle roofs with and without cool roof color materials.

Whereas, Elk is providing asphalt shingles at no cost for *Ochoa and Shehan* Construction to install on two homes in Redding CA in exchange for acquiring temperature, heat flow and power measurements for the two homes over the course of the two year field study.

ORNL personnel will instrument the two homes during construction slated for November 2004, and will monitor the homes over a two-year period ending Dec 31, 2006.

Whereas, Table 1 lists all the instrument measurements currently proposed by ORNL and Elk

Therefore, the parties agree to undertake the activities described below or otherwise agreed in writing during the course of the demonstration project:

DEMONSTRATION HOMES

1. **Ochoa and Shehan Construction** will make two demonstration houses available in 2004 for the field testing demonstrations described below.

INSTRUMENTATION FOR EACH HOME

2. **ORNL** personnel shall make 2-ft by 2-ft sandwich test panels of the same material as used for the roof decks at the demonstration homes, probably oriented strand board (OSB). Each sandwich panel will be made of two sections equaling the same thickness as the rest of the deck. The two panels will sandwich thermocouples and a heat flux transducer for measuring thermal performance of the roofs. A spare thermocouple will be included for possibly measuring the surface temperature of the shingle roofs.

3. ***Ochoa and Shehan* Construction** will notify ORNL of the start date for constructing the roof decks, and **ORNL** shall ship sandwich test panels to *Ochoa and Shehan* Construction prior to the specified start date.

4. **ORNL** will contract *Ochoa and Shehan* Construction to install the sandwich test panels as part of the deck for the test roofs. The orientation of the homes makes it necessary to use two panels per house.The roofing contractor will center and attach one panel to preferably a south-facing roof and center and attach the other to preferably the north-facing roof.

5. **ORNL** personnel under the supervision of *Ochoa and Shehan* Construction shall instrument the attic for measuring the attic air temperature and relative humidity and the temperatures around the ceiling insulation as well as the ceiling heat flux. A temperature and relative humidity probe will be mounted in the return duct to measure the return air temperature and relative humidity from the house (see Table 1 for a listing of measurements).

6. **ORNL** personnel under the supervision of *Ochoa and Shehan* Construction will install two Model WNA-1P-240-P Wattnode transducers for measuring the power draws of the two HVAC units. The meters shall be housed in weatherproof NEMA enclosures and placed on an exterior wall near the power panel for each home.

7. **ORNL** personnel shall install two pyranometers, one on the south facing roof and the other on the north facing roof of each house in an inconspicuous place near the roof ridge. The instruments have about a 3-in diameter and stand about 2-in off the roof. Instrument wires will be hidden by running them through the ridge or louvered vents into the attic and down inside an exterior wall to a data acquisition system (DAS) housed in a white plastic NEMA enclosure.

DATA ACQUISITION SYSTEM

8. **ORNL** personnel under the supervision of *Ochoa and Shehan* Construction shall install a data acquisition system on an exterior wall of each house (near the power panel) and shall make all instrument connections to the DAS. Placement of the DAS in the attic is not encouraged because problems do occur even with the best DAS and placement on an exterior wall near the power panel would cause the least hassle for the technician and the least intrusion for the homeowner.

   We will use a Campbell Scientific Model CR10X-2M micro-logger with model AM25T multiplexer for expanded channel capability. The DAS shall be in a NEMA 4 weatherproof and lockable enclosure. The DAS shall have 2 megabytes of extended memory, a phone modem, modem surge protector and rechargeable battery. The battery requires a 115 Vac source and therefore ORNL requests the DAS be placed near the power panel for obtaining the necessary instrument power. *Ochoa and Shehan* shall provide an independent phone line for communicating with the DAS.

9. **ORNL** shall fully program the DAS and shall fully document the data acquisition code for use in later trouble shooting problems by ORNL or LBNL personnel.

10. **ORNL** with support from *Ochoa and Shehan* will direct the phone service to run independent phone lines for hook up to each DAS for transmitting data by modem. These lines will be completely independent of the homeowner's phone system, and shall remain intact for the 2-year field demonstration. ORNL shall pay monthly charges incurred by *Ochoa and Shehan* Construction for the phone service to each data logger.

11. **ORNL** shall weekly check the data string output by the DAS received over the modem, and shall take responsibility for damage to the DAS and instruments, and will themselves make appropriate repairs.

AIR TIGHTNESS OF HOUSES (OPTIONAL-DEPENDENT UPON PERMISSION OF HOMEOWNER)

12. **ORNL** under the coordination of *Ochoa and Shehan* Construction and the homeowners shall have the option to measure the air tightness of the demonstration homes using a Minneapolis Blower Door test apparatus. A Duct Blaster™ apparatus will be used to check the tightness of the air duct system. Both outside air infiltration and duct leakage will affect air conditioning performance therefore we will attempt to document the tightness of the two homes. The air tightness of the house and ducting shall be checked after *Ochoa and Shehan* has completed construction but before the homeowner occupies the homes.

13. **ONRL** also requests the opportunity to conduct the air tightness testing at conclusion of the two-year study, and will coordinate the testing per the approval of the homeowner.

ONSITE REFLECTANCE MEASURES

14. **ORNL, LBNL** or Elk personnel will visit the site semiannually to measure the reflectance of the test roofs. The measures will require personnel to climb up a ladder to the roof and make the measurement, which will take only about 15 minutes.

THERMAL SCANS OF HOUSES

15. **ORNL** personnel request the opportunity to make thermal scans of the homes to judge the relative effectiveness of the roofing systems once the homes are built and occupied. As the roof systems age the thermal scans will help document the overall thermal performance of the roof as compared to their starting performance. The scans are taken outside the home and will be conducted yearly.

COMPOSITION SHINGLE RETRIEVAL

16. **ELK** personnel request the opportunity to remove and replace one possibly as many as three shingles from the roof facing the back of each home on an annual basis. Elk will take the field exposed shingles and conduct chemical and mechanical (tensile and flexural) testing to check for changes in the chemical and physical properties of the two different types of shingles. Elk will conduct a Corbett fractionation procedure to show the molecular size of hydrocarbon fractions and will also conduct gel permeation chromatography to show the %weight distribution. Both tests will confirm the loss of naphthenes aromatic oils and the gain of asphaltenes. Results will help confirm that the new shingles with CRCMs perform in a consistent manner with existing standard

production shingles. Appropriate data shall be shared with ORNL for support of the CEC work contracted to ORNL and LBNL.

VISITATION

17. The homeowners shall agree to allow visitation privileges to ORNL, LBNL or ELK personnel in case of maintenance, repair, routine checks of instruments or the DAS. However, all visits will be coordinated through Ochoa and Shehan Construction or the homeowner's permission to egress said property. Therefore personnel shall schedule visits amenable with the homeowner prior to the actual visit. Visits will be limited to field acquisition and or checks to trouble-shoot instruments and or the DAS.

18. At completion of the two-year study **ORNL** will remove the DAS, instruments and wires with exception of those embedded in the roof deck.

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Appendix C

Table C.1. Instruments specified for measuring the building envelope thermal performance of each house.

INSTRUMENT	*Description*	Location	Attachment	Channel	
South Facing Roof					
Thermocouple (Type T Cu/Con)	26 AWG Unshielded bead	Spare for Roof Surface	Epoxy	8 T	
"	26 AWG Unshielded bead	Deck	Taped	7 T	
"	26 AWG Unshielded bead	In Deck	Embedded between OSBs	6 T	
Heat Flux Transducer	2-in by 2-in by 0.125-in thick	In Deck	Embedded between OSBs	2 Rd^{+}	
Pyranometer Li-Cor	Solar Probe	Near ridge at roof gable	Mounting bracket	4	
Thermocouple (Type T Cu/Con)	26 AWG Unshielded bead	Deck underside	Taped	5 T	
North Facing Roof					
Thermocouple (Type T Cu/Con)	26 AWG Unshielded bead	Spare for Roof Surface	Loctite Epoxy	4 T	
"	26 AWG Unshielded bead	Deck	Taped	3 T	
"	26 AWG Unshielded bead	In Deck	Embedded between OSBs	2 T	
Heat Flux Transducer	2-in by 2-in by 1/8-in thick	In Deck	Embedded between OSBs	1 Rd^{+}	
Pyranometer Li-Cor	Solar Probe	Near ridge at roof gable	Mounting bracket	5	
Thermocouple (Type T Cu/Con)	26 AWG Unshielded bead	Deck underside	Taped	1 T	
Attic interior					
Vaisala 50Y	DB & RH Probe	Attic air 4-ft above insulation	Run along support wire	6	
Thermocouple (Type T Cu/Con)	26 AWG Shielded bead	Top of insulation	Laid atop insulation	10 T	
	26 AWG Unshielded bead	Sheet rock surface facing attic	Taped	9 T	
Heat Flux Transducer	2-in by 2-in by 1/8-in thick	Sheet rock surface facing attic	Sandwiched between insulation and sheet rock	3 Rd^{+}	
House exterior above ridge vent (Not Applicable)					
Vaisala 50Y	DB & RH Probe	Ambient air 3-ft above roof	Mounting bracket	NA	
Anemometer	Wind velocity	Ambient air 3-ft above roof	Mounting bracket	NA	
Wind Vane	Wind direction	Ambient air 3-ft above roof	Mounting bracket	NA	
House interior					
Vaisala 50Y	DB & RH Probe	Entering return grill	Duct mounted	7	
Thermocouple (Type T Cu/Con)	26 AWG Unshielded bead	Leaving evaporator coil	Run along support wire	11 T	
Wattnode transducer	Model WNA-1P-240-P	HVAC Power	NEMA enclosure on exterior wall	8	———
Wattnode transducer	Model WNA-1P-240-P	HVAC Power	NEMA enclosure on exterior wall	9	———